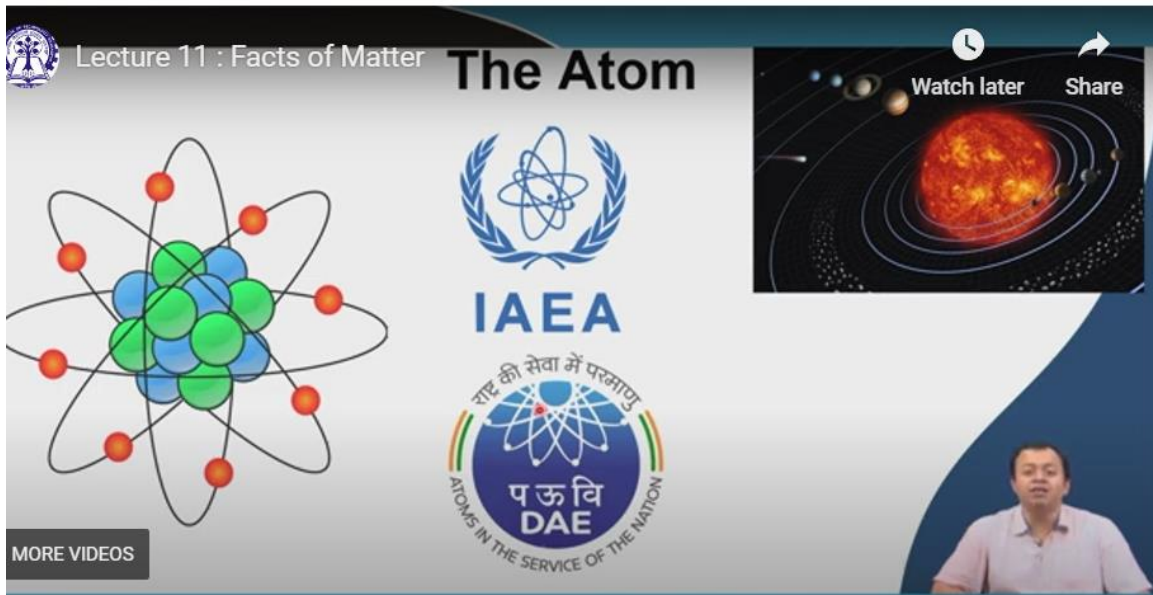**Nanobiophotonics: Touching Our Daily Life**
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Lecture No. 11
Facts of Matters

Hello and welcome to the course of nano biophotonics touching our daily life. This is the beginning of chapter 3, another preliminary where we basically discuss how nanotechnology and photonics matter to disease detection and the type of works that we believe nano photonics has a potential to do. Now again since this is preliminary the last preliminary I promise, we will discuss about the very basic of nanotechnology. Here since nanotechnology is an entire field people make their carriers out of it, I be one of them. I would like to keep it specific towards photonic application of nanotechnology. But nevertheless I will be giving you the basic background of what nanotechnology is and how it works and why it should be interesting to you.

Now before we go into nanotechnology we all know where we have to start with. We have to start with the atom right. This is an atom you know there is a nucleus and there are electrons revolving around it. We see this image in several scientific places International Atomic Energy Association as well as the Department of Atomic Energy of the Government of India where we have train tracks.

These are like train tracks around which this is the specific specific path which electrons follow around a proper nucleus in order to exist in order to sustain very much similar to how in a particular orbit planets revolved around the sun. Now let us clear some misconception first. Firstly, what are atoms? Atoms make up everything. Every single matter in this universe is made up of atom. Everybody knows this.

You have read it in high school, middle school, text books, your high school teacher, your chemistry physics teacher everybody had told you this. Matter is made up of atom. Atom is the smallest part of matter. All of you know this. Wrong.

Wrong. Wrong. Wrong. Not all matter are made up of atoms.

Yes. Yes. You were wrong. Your high school teacher were wrong. The text books were wrong. I was wrong.

73 percent of the universe this universe that we know is comprising of dark energy. 23 percent of the universe comprises of dark matter. Star matter that is planets, galaxies, etcetera star based matters are just 4 percent. We higher life form at 0.

03 percent. Dark matter and dark energy which covers the entire universe almost entirety are not made up of atom. Are not made up of atom. You ask what they are made up of. I do not know, but they are most definitely not made up of atom. They simply do not interact with any sort of electromagnetic waves.

How do we know? We know by mathematical calculation. They exist because if they do not exist, the mass of the galaxies, the number of stars that are present in galaxies are simply not enough to keep the galaxy in place. The galaxies are massive massive structures, celestial bodies containing millions and billions of star systems, but still their masses are so small that they cannot hold the galaxy together. The galaxies are held by something much complex which are called dark matter. Dark matter is not made up of atoms.

So, the majority of the universe is the majority of matter in the universe is not made up of atoms. Only less than 4 percent of the universe is made up of atoms. We deal with that 4 percent. To the best of my knowledge, if I could speculate none of you are going to get away from this galaxy anytime soon. So, let us stay here.

Let us stay into this planet. Perhaps solar system could be in 50-60 years. Somebody may live in Mars 70 years from now, but it is still star matter and thereby atoms are still relevant. But remember this misconception not every matter is made up of atom. The majority of matter in the universe is dark matter which do not interact with electromagnetic waves.

It do not interact with us. It is made up of something completely different which we have yet to find out experimentally. We have calculated it and all our calculations are telling that they are not made up of normal matter. Enough astronomy.

Let us come back. So, first misconception was that. Second misconception everybody knows this sign and everybody thinks that electrons have a fixed path like train tracks like orbits and they move around it. If they have a fixed path around the nucleus, then it was very easy to determine both their position as well as velocity. You can do it anyways. They are not going anywhere away from this.

They are moving with a particular speed. You know the exact distance. You can figure out the time speed is equal to distance by time. You know the speed. You know the distance this entire distance and you can figure out at what time this electron will arrive at what specific position.
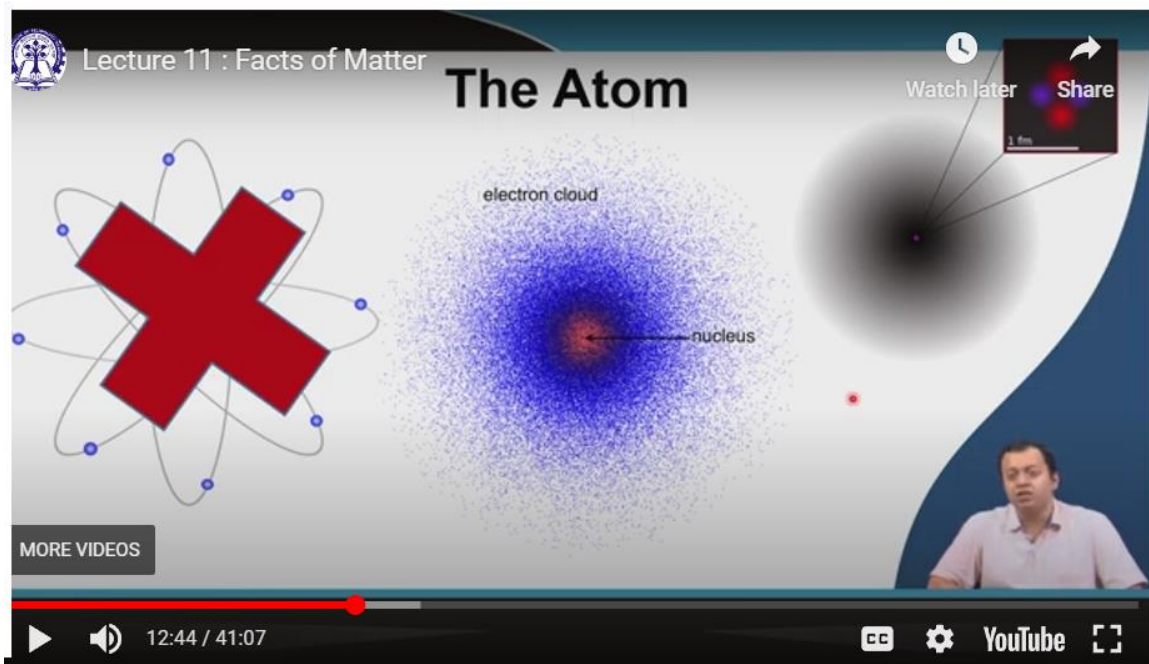
So, why do we use this? We use this as we will see that this is a very cool image. This is a very interesting image people like to see because the actual image is quite complex. People tend to stay towards the easier part. Fact of matter remains that instead of having train tracks running around the nucleus in which electrons run, the actual position of the electron is more or less distributed probability wise around the nucleus. So, understand what I mean this probability part is very important and you have to have to understand it thoroughly.

Remember this. Repeat after me if you can. Chance of occurrence does not mean occurrence. What does that mean? You go for the weather forecast. Tomorrow from 6 o'clock to 8 o'clock in the morning, there is a 90 percent chance of rain. Does that mean that there will be rain? How many times it has happened to you that you have taken an umbrella looking at the forecast in newspaper or radio or television stating that there will be rain and it did not rain.

There was a chance there was a possibility of rain, but it did not rain. So, the probability was there the chance of occurrence of rain was there, but chance of occurrence does not mean occurrence. The probability 90 percent probability does not mean there was rain. So, the idea here is that if there is a nucleus and if you have put a camera around the nucleus and you have kept on recording in an environment in and around the nucleus for a very large period of time and every time an electron moves around, you have got a hit on your camera. Every time there is a group of electrons moving around in specific direction specific   path,   you   have   got   a   hit   around.

Then you have compiled all those images every second every millisecond for 1 year, 2 year, 3 year, 10 years and then you have distributed that there is a very good chance of rain happening the electron coming at this specific position. There is a very little chance of rain happening at this particular time, this particular position. It is simply like that you have a camera at your backyard, you have taken the image of the sky each day every day for the last 5 years and you have compiled those images and thereby you have a huge database based on which you can predict you can forecast that usually June July it will rain September, October or December January depending on where you stay. I am talking about where I stay there will be less rain April may almost no rain. There are exceptions if I ask you that will say 5th of July at 10 am to 10 15 am will there be rain what will be your answer 90 percent possibility usually in July it rains, but it does not mean if you go precisely   you   might   miss.

On the other hand if I say instead of 10th of July 10 to 10 15 am if I say will in the month of July there will be rain the probability increases. If I ask you will this year there will be rain the probability reaches almost 100 percent right. So, the position of electron around a nucleus is bunch of probabilities you have large amount of atoms large amount of electrons all of that your probability increases, but if you are looking for individual atoms such as these and then trying to figure out where exactly one electron is located around the nucleus it is like trying to predict will it be rain on July 10th from 10 am to 10 10 am chances are you might get it right. We cannot say that they will never happen it does happen, but probability wise it is difficult right. So, understand what we see and this probabilistic path June July August there will be more rain less rain in the other times this probabilistic path is   what   we   know   as   orbitals.

Orbitals are different from orbits, orbits are fixed path around which planet travels around the sun or around the star orbitals are the probable path where the chance of finding electron is maximum it does not mean you will find it it does not mean it will rain most definitely right it may rain this may is very important. As soon as we see these images these images we tend to forget about it we have to understand the probability distribution

these are schematic as well as some scientific images which actually show the distribution the closer you come to the nucleus there are more probability the away you go from the nucleus there are less probability, but very close to the nucleus also you will have difficulty because then the electron may fall inside the nucleus. So, you have to have a probability distribution, but again chance of occurrence does not mean occurrence probability of finding an electron at a specific area specific region does not mean the electron is there you increase the area you increase the number of atoms you increase the number of electrons your probability will increase, but if you are looking the more precise you want to go your probability will start getting more. So, this needs to be carefully understood. Now, what is this probability function we talk about the probability function we are talking about which determines the position of an electron we are talking about electron though other elementary particles are also necessary how do we find out this probability function yes it is probability not definite, but can we have some amount of mathematical idea of where this probability is how the probability distribution is of this electron around the nucleus.

Well there was this gentleman called Erwin Schrodinger Schrodinger's cat famous was become famous for that it has become part of contemporary culture where Schrodinger decided to figure something out and he came up with this nifty little formula called Schrodinger wave equation in which he tried to figure out the probability distribution the probability of the existence of a particular elementary particle let us consider it electron for the sake of simplicity and what are its chances of existence at a particular energy at a particular space and time coordinate. All of you perhaps have heard of Schrodinger wave equation I am not going to derive it here medical students might not like it, but you got to understand the gist the meaning of it. So, stay with me and let me take you through what Schrodinger equation actually do. However, if you think quantum mechanics is not your cup of tea well I will be teaching you little bit tiny bit a hint of quantum mechanics in the

upcoming classes, but if you think you do not like quantum mechanics this is what Erwin Schrodinger who wrote the or who derived the Schrodinger wave equation which is more or less the base of any quantum mechanics text book any quantum mechanics field this is what he said I do not like it and I am sorry I have I ever had anything to do with it. So, if you think you do not like quantum mechanics well nobody actually does frankly speaking because it is counter intuitive or it is against everything that we have you know we perceive normally something is both on and off is difficult for us to imagine and it is not some kind of word play it is actually is and nothing is more nicely shown by this guy than this thought experiment where he thought put where he thought that I will put a cat in a box with ah vial of poison I think radioactivity inside the box the box will emit this radioactive ah at a at at every 50 years half year every 50 years, but you do not know when was the last time the emission had happened I am making it up I think it might be slightly inaccurate, but overall the idea is that without opening the box you do not know when the poison gets out of the box there is there is a small box inside the box which contains the poison or the radioactive material that can open any time and the cat will die it has radioactivity.

So, the cat will die ah. So, the idea here is that do you know if the cat is alive or dead without opening the box. So, the answer is that unless you open the box you will never be sure whether the cat is alive or dead because the poison vial can open randomly at any time not technically randomly it has a half life, but you do not know whether 50 years when was the last time the emission happen it it emits every 50 years when was last time it emitted you do not know. So, you have just put it. So, now, you have to speculate guess whether the cat is dead or alive he said then in quantum superposition unless the box is open you will never know and till you do not know the cat is simultaneously dead and alive the cat is simultaneously dead and alive because you do not know both the positions both the states alive and dead have superimposed. So, this was the idea and it gave rise to thousands of memes and ah hoardings and t shirts etcetera just Google Schrodinger's cat and   you   will   you   will   see.

The Schrödinger Equation

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi(x) = E\psi(x)$$

Time independent Schrodinger equation

The simplest example is a particle (say electron) in free space so, $V(x) = 0$, Therefore, the time-independent Schrödinger equation is

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} = E\psi(x)$$

 So, what actually Schrodinger equation state is that this is the wave function what exactly is the wave function. So, wave function could very easily be said. So, remember before coming to this you might suddenly ask what is wave function the square of wave function is the probability distribution. So, this $\psi(x)$ is the probability square of this term ψx square of this term is the probability distribution of finding a electron at a position x. We start with time independent Schrodinger wave equation which means that time does not matter you do not at this present moment you are not dealing with at what particular time the electron is there you are only dealing with space whether the electron is present at x y z coordinate right and you have simplified it to x y and z are for the time being for the time being I know physics people will scoff, but for simplicity this actually go as $\psi x \psi y \psi z$ or ψ x   y   and   z,   but   I   have   simplified   it   to   psi   x   only.

  So, ψx is the square root of the probability distribution this is much more interesting this is the wave function and this somehow amplitude of the wave function you can say this somehow tells the overall existence of a particle with specific energy with total energy E at a coordinate x y and z for the time being are removed. So, x is a distance with respect to reference. So, this is the overall energy of the electron overall wave function of the electron that could be found where $\hbar^2$ is reduced Planck's constant E= hν. hvis Planck's constant $6.6\text{X}10^{-34}/2\pi$. you will get this m is the mass this is the double differentiation of this ψx I think there should be x here there should be an x term here this v is the potential energy E is the total energy E is the total energy. So, what I will simplify it I will simplify it.

 For the simplest example if the particle say electron is moving at a at a particular space where you have taken the potential energy to be 0 and only moving x therefore, only kinetic energy there and some other energy is there the kinetic energy is there the overall

probability distribution whether you will find it or not some degree of understanding of the probability of existence of the electron with a total energy E at a space at a coordinate x it is moving around particular coordinate x y and z for the time being is considered 0 for simplicity is given by this particular formula that is it that is the beginning it is not that hard it is not that hard the hard part will come later let there be no ambiguity the hard part will come later when you will rationalize it because it gives you it throws up so many different things, but overall what does Schrodinger wave equation tells you in very very simplistic term Schrodinger wave equation simply gives you simply gives you an information about whether a particular electron of particular specific energy has a possibility of existing at a specific area at a specific region this is time independent. So, I am not talking about time at a specific area specific region specific distance in and around free space or under certain conditions free space is free space there is no external pressure temperature energy on it bound state is where you have put it close to the nucleus of an atom or put it close to more than one nucleus of an atom in a lattice in an atomic surrounding. So, this is what they actually tried to derive simplistically very very simplistically by doing this so called thought example particle in a box you have put an electron in a box or in a well the potential energy outside the well is infinite the potential energy inside the well is 0 and you have put an electron in a box the box has a length of L. So, the x is from 0 to L this is the length of the box. So, the box has a finite length L and this wall is infinite.

So, many times they say that particle in a well you know the water well which has a small hole length, but infinite up and a very small the electron cannot go near the wall it has to stick to the wall. So, now, certain conditions are given certain conditions are put into this this particular case you have direct given certain conditions that V x = 0 the probability of having the electron near the wall at x = 0 and x = L. So, electron only has to stay in between that it cannot it cannot touch 0 and go beyond negative it cannot touch L and go L plus 1

L plus 2 or whatever L plus 0.01 it has to stay in between it touches the wall it dies it cannot go out it is inside. So, you have imprisoned the electron you have imprisoned the electron that is the condition consider it as an electron near a nucleus.

 If you put the electron very close to the nucleus one particular wall the electron will fall into the nucleus and it will probably destroy probably get attracted something will happen or if the electron is too far away from the nucleus it will simply it will simply not get bounded by the nucleus and it will fly away. So, the electron is put in certain conditions that you cannot move from this area or it cannot move from this area in an area I have imprisoned you I have restricted you when you cannot touch the walls based on that conditions if you solve this particular equation you get this particular formula you get this particular formula where you find out that electron then re restricts itself electron further restricts itself into discrete energy levels. The most interesting thing about these energy levels that these energy levels are always discrete 1 2 3 4 what does that mean what exactly that mean I am teaching remember quantum mechanics without touching mathematics per say because I know biology or medical students will not like it and you do not need to like it let us see if I can try to explain it without mathematics. Meaning whenever an electron has been put inside some restricted movement area it distributes itself it distributes itself into specific levels it distributes itself within the imprisonment within the present cell into specific level where it can exist and where it cannot exist it can exist in areas which are 1 2 3 4 given by this particular formula n equal to 1 2 3 4 l is this length m is the mass h is the Planck's constant. The solution of this when you put this particular condition on to this the solution is available in any physics textbook I have given it here if you want to go detail   try   it.

  So this is the overall specific property Schrodinger wave equation states that whenever an elementary particle is put inside a present cell put inside some kind of energy boundary condition it arranges itself into distinct level these levels are discrete they cannot be continuous and they are different energy levels just like a ladder most like a ladder consider it as a ladder you know ladder has two boundaries but then steps you can only put your feet in one step or the other you cannot put your feet in between the steps where is air. So electron similarly arranges itself into a ladder like structure into a ladder steps like structure it can only exist in steps and just like in ladder there are step 1 step 2 step 3 step 4 there is no no 1.05 step there is no 1.238 step it is always step 1 step 2 step 3 step 4 1 2 3 4 you can only put your feet in step 1 step 2 step 3 step 4 you cannot put your feet in step 1.28 think about the stairs that take you from ground floor through first floor I ask you to go and sit at stair number 4 can I ask you to go and sit at stair number 4. 68 does it exist no even in this particular case. So there are specific specific steps specific specific levels where electrons can exist this is what Schrodinger wave equation is telling us these areas are where you will have the maximum probability of finding an electron not

necessarily you will find an electron but they have the maximum probability in between them 1.2812.63 you will have very little conditions very little probability almost touching 0 of finding an electron maybe one is in motion you might find but that is also let us not let us let us not go into that direction all together. So, there are gap the ΔE between the two successive levels is given by this particular formula and they actually forms the orbitals they actually forms the orbitals of an atom orbitals are the steps obviously, you have to use your imagination that this is simply two dimensional there is length only in one direction. Obviously, you will have to have in an atom there is three dimensional restriction it cannot have infinite in y direction z direction does not exist and x is only l in an atom it is   three   dimensional.


But nevertheless the steps are these orbitals 1 s 2 s 2 p 2 p y where the probability of finding the electron is maximum all right. And if that camera actually is put near the nucleus and every time the electron is moving around and you are getting a hit this is the overall image that you will probably get. So, the spherical are usually the s orbitals the p orbitals are usually dumbbell shaped, but tell me which image was cooler this or the previous one with the train tracks the previous one with the train tracks are much cooler image. So, people still use it, but actual the probability distribution of electrons around a nucleus maybe could be very nicely be represented as this. But it also shows that there is a quantized state quantized means that electrons with all probability will exist in specific areas   it   will   not   exist   anywhere   randomly   around   it.

At the same time you will have a high chance of finding an electron here not necessarily you will find it there is a high chance of having rain in July not necessarily you will have rain in July at 10 o clock on July 10th understand this chance of occurrence is not equal to occurrence. So, then comes the term that why do atoms bond to create molecules what was the point of having atom create molecules chemistry student will say the valence last few

what was the thing again the outermost orbitals needs to be fulfilled and you need to get 8 etcetera. So, do you think the noble gases exist in individual atoms helium neon xenon krypton they exist individual atom they do not form molecules are the individual atoms around xenon exist xenon gas exist as simply atoms what was the requirement of electrons to come together or what was the requirement of atoms to form molecules why form molecules and if form molecules why are you not satisfied with one carbon form. So, many molecules why is one not enough well if you look from a quantum mechanical point of view. So, this is the overall distribution say hydrogen has an electron cloud electron cloud oxygen has an electron cloud and they have combined together and they have redistributed the idea here is see the energy is inversely proportional to length right the energy is inversely proportional to length I will go back the energy here is inversely proportional to length meaning if I increase the length the energy will reduce if I decrease the length the energy will increase yes why you should be interested to know that because when two atoms come together and electron is shared previously this electron was moving previously this electron was moving around this atom previously this electron was moving around this atom previously this electron was moving around this atom, but now that they have made the bond the electron can move around the entire different nucleus because the electrons are shared meaning the length has increased the restrictive length has increased if the length has increased then energy has decreased it is the fundamental characteristics of every single matter except dark matter dark energy every single normal matter to reduce its energy to come to the stablest position nothing likes to stay in high energy state everyone is always trying to reduce energy atoms reduce energy by forming molecules molecules allow the electron to move at a larger distance and this larger distance overall reduce their energy make them simply more stable that is the only reason or that is the fundamental reason atoms bond to create molecules to lower their energy every particle every matter except dark matter wants to reduce energy I have to be careful because I also used to say everything is made up of atoms every matter is made up of atoms now I have been corrected and I hope that I correct you too.

Electronic State of Molecules
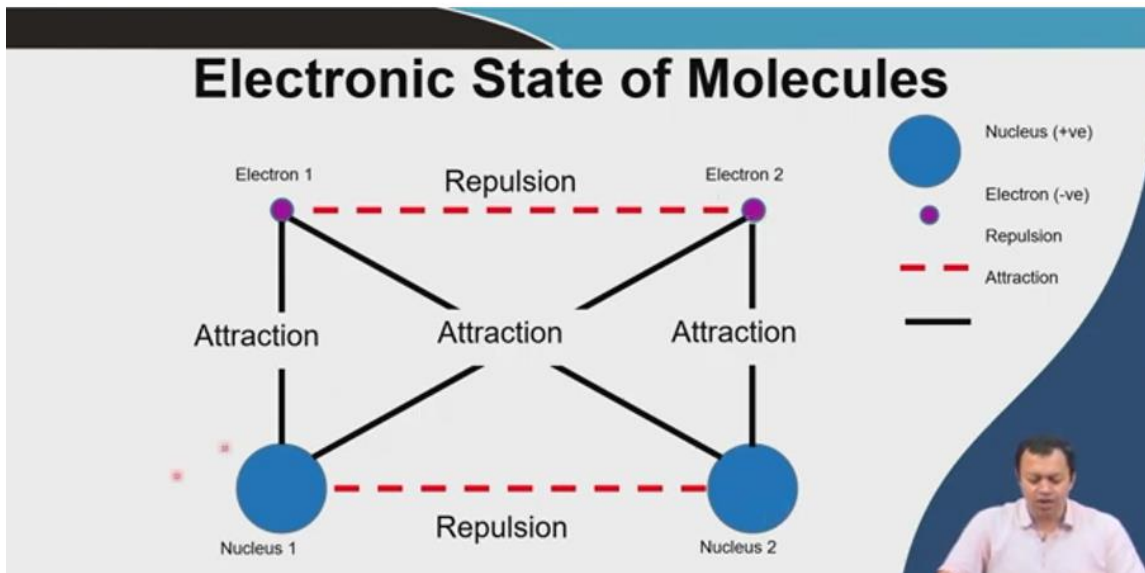
So, in the electronic state of molecule understand this that if we are talking about two diatomic the simplest thing this is hydrogen nucleus connected with a one electron this is another hydrogen nucleus nucleus number two connected with another electron when they come together there is a combination of attraction and repulsion forces this nucleus will attract nucleus one will attract electron one nucleus one will also attract electron two nucleus two will attract electron two nucleus two will also attract electron one at the same time there will be forces of repulsion between the two nucleuses and there will be forces of repulsion between the two electrons. Now depending on which of these forces prevails attractive forces win or repulsive forces win determines whether these two atoms will bond or not many times in order to bond the electrons or the atoms beg your pardon the atoms have to rearrange themselves in three-dimensional space so that the columbic attraction becomes such that the net the net force is attractive rather than repulsive what does that mean you know coulombs attraction force is q 1 q 2 by r square so force is directly inversely proportional to r right the force of attraction force of repulsion. So, this r has to be somewhat the r has to be somewhat the distance between two charges which are close to one another such a way they have to be physically arranged the atoms have to physically arrange in a three-dimensional space so that they can form overall attractive forces higher and thereby the bond forms if the attractive forces are not here not higher than the repulsive forces if the repulsive forces win then there is no bond there is absolutely no bond and you will not have molecules you will have individual atoms. So, when we give energy to an electron it moves from this position to a higher position so the force disturbs f is inversely proportional to r square so the force of attraction and repulsion columbic forces of attraction and repulsion disturbs and if that disturbs and a distribution has taken place maybe the bond is already broken how do you break bonds you supply energy what happens to the energy the energy is absorbed by electrons it goes from one level to another level and this entire force of attraction collapses there is repulsive forces and that is it and that is how the atomic orbitals are overlapped we have sigma bond and we have pi bond

two atomic orbitals are coming together either they will repel one another or they will attract one another attraction one another overall reduces the energy repulsion that increases the energy and you have anti bonding here L is high the electron can moves at a higher area so overall energy is low here electrons have to move in a lower area
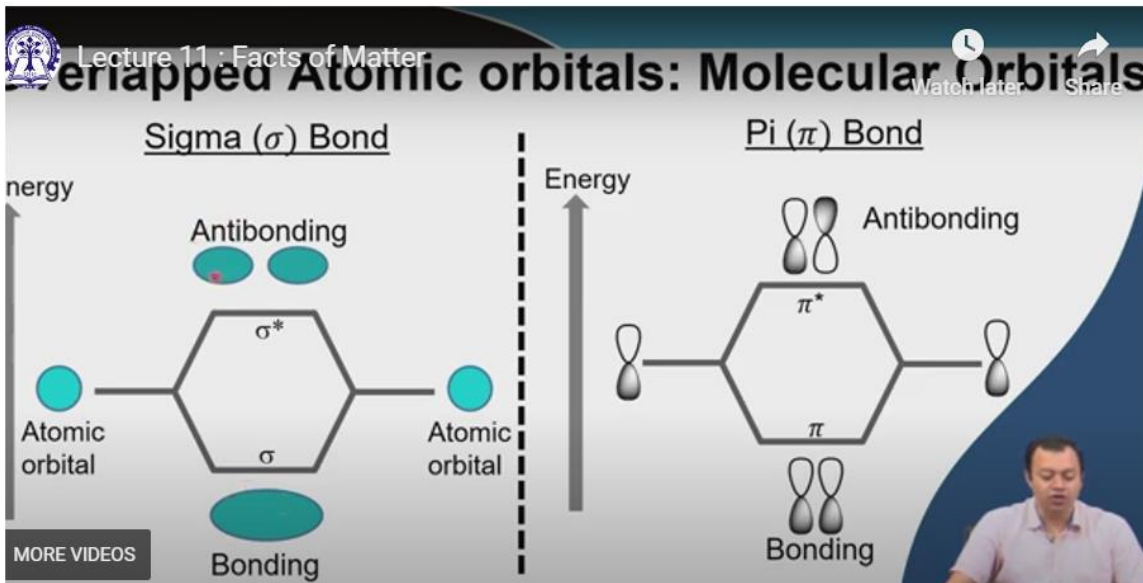
because they have repulsed each other and thereby you have anti bonding so anti bonding is always high energy so if your electron is moving here if your matter is here you supply energy take it above you break the bond anti bonding is where no bonding happens similarly this thing is happening in pi bond as well the s bond and p bond s orbital and p orbital that you saw so hydrogen has s orbitals they come together and they can form H2 if this is happening you supply hydrogen with enough energy it will combust and that is anti bonding similar is for p bonds complex structures forms complex bonding forms when you have s molecules which are having 1s and 2s combining with p bonds and pi orbitals especially in the case of complex conjugated molecules which has hydrogen nitrogen carbon and the overall electronic distribution electronic cloud distribution is in a much more complicated way the atoms have to distribute rearrange themselves in three-dimensional space in such a way that this is attracting this but this is actually repulsing this this in terms is attracting this so the overall bond formation the overall net is enough enough enough attraction between them but since it is so complicated this electronic cloud distribution a minimum amount of energy into conjugated molecules organic molecules like us is capable to break this complex nature and thereby the material do not survive how much heat as I say your body can survive 70 degree 80 degree can you survive 100 degree

Celsius think about it how much complex chemicals are present in your body that has created it hydrogen nitrogen oxygen this that overall system is like this the electrons have to come together some amount will be repulsion some amount will be attraction the overall net result has to be attraction that will reduce the overall energy any extra energy from outside can result in breaking of this equilibrium breaking of the equilibrium breaking of that matter organic materials have very very complex structures because they have different s p and all of those orbitals combining together and thereby they are forming this complicated structures which is very very fragile any external energy source can destroy

our idea is to keep things at the edge send light make it at the edge of breaking and then bring it back if we can manage to do that if you can manipulate it we have a fantastic

system to study so these are the conclusions energy levels of atoms are quantized both light and matter exhibit in dual nature and constructive overlap of atomic orbital produces bonding destructive overlap destructive overlap repulsion constructive overlap is attraction they produces anti bonding.

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so these are my references thank you very much ..